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A selective bibliography of papers published between January 1965 and December 1969 on shallow water acoustics and sonar

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A SELECTIVE BIBLIOGRAPHY OF PAPERS PUBLISHED BETWEEN JANUARY 1965 AND DECEMBER 1969 ON SHALLOW WATER ACOUSTICS AND SONAR

by

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ABSTRACT:

A survey was conducted of that literature relevant to the propagation, detection, and utilization of acoustic signals in the shallow water environment which was published between January 1965 and December 1969. For the purpose of this survey, shallow water was defined as water of depth less than 100 fathoms. This survey is divided into the following areas: normal mode propagation - theory and experiment, ray theory propagation - theory and experiment, bottom acoustics, bottom scattering and reverberation, surface scattering and reverberation, shallow water ambient noise, signal distortion in shallow water, attenuation of sound in shallow water, sonar tests in shallow water, and review and miscellaneous articles. Abstracts, when available, are given for each paper; comments are included.

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PART I

GENERAL COMMENTS

This bibliography has been undertaken at the request of the ASW Studies Group of the Naval Postgraduate School, the compilers serving as members of that group. An earlier version of this report (61KS9101B, 10 October 1969), prepared for the Naval Air Systems Command, contained information classified CONFIDENTIAL. The present version, prepared to facilitate dissemination of the unclassified material in that report, has been updated by inclusion of additional comments and consideration of more recent publications.

The purpose is to provide a useful listing of those results published in the interval 1965-1969 containing important contributions to the propagation, detection, and utilization of acoustic signals in the shallow water environment; a specific objective is to provide the civilian industry and the Naval establishment with an overview of the technical publications in this five-year interval.

While it has been the goal of this endeavor to be selective in choosing those titles to be included, we recognize that others may judge relevance quite differently, and so remind the reader that the selection has been made, in the last analysis, on the basis of personal taste. Furthermore, the comments which have been appended to the references reflect the personal opinions of the the compilers and must be interpreted in that light.

A number of specific areas have been excluded:

1. Finite amplitude effects.

2. Signal analysis approaches. Exceptions have been made when the development is sufficiently close to the realities to offer some positive contribution to propagation in shallow water rather than unrealistic or oversimplified modeling thereof.

3. Artic Ocean. Since this topic merits a complete bibiliography of its own to do justice to the special propagation problems encountered under ice, only those papers which contribute to the general shallow-water problem have been included.

4. Strictly theoretical treatments. While these papers are often of utmost importance in opening and furthering new avenues of approach to the problems, they are assumed to be of lesser interest to the expected audience. These papers are well-referenced in the included papers and can be investigated by the interested reader.

A. NORMAL MODE PROPAGATION - THEORY

New theoretical work in the field of normal-mode propagation in shallow water has been concerned with extending the theory into more complicated situations. The analysis of A1 reveals the large signal fluctuations over short ranges to be expected from modal interference. A2 extends the theory to a bottom of constant slope and predicts a modified cylindrical spreading at long ranges. A3 is concerned with interchanges of energy between modes as caused by scattering by rough boundaries. Paper A6 develops and extends these considerations. A4 develops the theory for propagation in shallow water with a negative velocity gradient. In particular, it supports some of the intuitive judgments that have led to semi-empirical models for sound propagation in shallow water.

B. NORMAL MODE PROPAGATION - EXPERIMENTAL RESULTS

This extensive group of papers is concerned with the recent increasing effort to check experimental measurements of propagation loss in shallow water against the predictions of normal mode theory. B2 and B5 report on an interesting comparison between measurements made in one area, first under isovelocity conditions and second under a negative velocity gradient. Some three to four modes were required in order to predict propagation losses beyond 10 miles. B1 makes the not surprising conclusion that mode theory is superior where ray theory predicts caustics or shadow zones. One feature of note in these papers is the increasing popularity of the Epstein velocity - depth profile for representing realistic velocity gradients. B9 is particularly interesting in its demonstration that a small change in water depth may change transmission loss by 15 db. This change is supported by either image or mode theory as a phase cancellation phenomenon.

C. RAY THEORY PROPAGATION - THEORY

The listing of seven papers under the above heading confirms the continuing importance of efforts to expand and refine the use of ray tracing as a means of predicting and explaining acoustic propagation in shallow water. New developments include calculations for sloping bottoms (C1 and C3), bottoms having curvature (C6), rough bottoms (C4 and C6), curvilinear velocity-depth profiles such as the Epstein profile (C2 and C5), and the use of numerical integration techniques in computing acoustic intensities (C7). Unfortunately, the complexity of the mathematics and the variability and lack of knowledge of the physical parameters involved make unlikely any practical operational utilization of the transmission loss prediction techniques described in these papers.

D. RAY THEORY PROPAGATION - EXPERIMENTAL RESULTS

This group of papers includes two new prediction models (D1 and D4) for shallow water sound transmission along with experimental evidence for their validity. When the two models are applied to a given situation, their predictions are found to be equivalent. The model described in D1 can be applied to a greater variety of water and bottom conditions than can that of D4. Papers D2 and D3 contain unclassified material on 3.5 kHz propagation taken from K2, which is concerned with SQS-26 Sonar Tests in Shallow Water under downward refraction conditions. The paper D3 is particulary interesting in its criticisms concerning detailed ray-theoretic methods, their predictive abilities, and their practical utilities.

E. BOTTOM ACOUSTICS

Papers E1 and E2 contain comparisons between measured bottom reflections and predicted values assuming a multi-layered absorbing bottom. A multi-layer bottom with attenuating layers is required in order to predict correctly the reflection characteristics of the bottom. Papers E3 and E6 are concerned with laboratory measurements of sound velocity and attenuation in various sediments. Unfortunately, most of the measurements are at frequencies above 10 kHz. No real knowledge exists as to sound attenuation in sediments at frequencies below 3 kHz. Paper E7 indicates that velocity and attenuation measurements made in the laboratory on core samples may differ markedly from "in situ" values. This is a very unfortunate situation. Paper E4 is an excellent summary of current knowledge of bottom acoustics.

F. BOTTOM SCATTERING AND REVERBERATION

Paper F1 contains considerable significant experimental data as well as pertinent equations relative to the magnitude of bottom reverberation in shallow water at those frequencies used in EER. Much interesting data are included in F5, but unfortunately at 48 kHz, a frequency of interest in mine detection rather than submarine detection. Included in this section are papers concerning deep water if grazing angles less than 5° are discussed.

G. SURFACE SCATTERING AND REVERBERATION

The papers included in this group indicate that our ability to predict surface reveration has advanced much more than our ability to predict bottom reverberation. G3 is an excellent summary of the theory involved. The other papers contain both theoretical discussions and experimental data.

H. SHALLOW WATER AMBIENT NOISE

This problem is too complex and the pertinent data too scarce to allow any systemization at this time.

I. SIGNAL DISTORTION IN SHALLOW WATER

Paper I4 is concerned with signal distortion caused by one reflection from the sea bottom. I3 and I7 discuss theoretical influences of multipath propagation on correlation detection of echoes. Conjectured optimum waveforms are derived for both noise-limited and reverberation-limited situations. Much more development must be accomplished before signal-analysis techniques will show any profit in treating the ocean as a four-terminal network. I6 gives experimental data on phase stability of acoustic propagation shallow water. The series of papers I9-I11 constitute the results of over a decade of serious study and careful observation. I11 is particularly to be recommended for study. In general, these papers indicate that signal distortion is more serious in shallow water than in deep water.

J. ATTENUATION OF SOUND IN SHALLOW WATER

Paper J1 is more concerned with problems of mine detection in shallow water than with submarine detection. The remaining three papers give examples of additional attenuations of unique importance to shallow water propagation resulting from the presence of fish and air bubbles.

K. SONAR TESTS IN SHALLOW WATER

Paper K2 is an outstanding example of a report on sonar tests which not only includes information on detection ranges but also much detailed information on those fundamental parameters, e.g. shallow water propragation and reverberation, leading to the observed detection ranges.

L. REVIEW ARTICLES

Each of these papers contains important information on sound propagation in shallow water.

M. MISCELLANEOUS ARTICLES

These papers were not available for review or comment.

PART II

DETAILED ABSTRACTS AND COMMENTS

A. NORMAL MODE PROPAGATION - THEORY

A1 NORMAL-MODE INTENSITY CALCULATIONS FOR A CONSTANT DEPTH SHALLOW-WATER CHANNEL

H. P. Bucker and Halcyon E. Morris
J. Acoust. Soc. Am. 38, 1010-1017 (1965)

Abstract: Normal-mode theory is used to calculate the propagation of sound at moderate-to-long ranges in a realistic, constant-depth, shallow-water channel. The channel is made up of two isovelocity water layers lying over a layered viscoelastic solid bottom. The equations for the sound intensity are written in rather simple form by using Brekhovskikh's formulation in which the effect of the channel bottom enters the equations as a single reflection coefficient. Because the bottom sediments absorb some sound energy at each bottom reflection, each of the modes has an exponential attenuation as well as the usual $r^{-1/2}$ spreading loss. In this paper, these mode-attenuation constants are calculated exactly - i.e., to any desired accuracy - by an iterative process. Reasonable agreement is shown between calculated values of propagation loss and some experimental values from a recent sea test by the U. S. Navy Electronics Laboratory. The introduction of a directional source into the calculations is briefly discussed.

Comment: The normal mode solution contains considerable structure, equivalent to about 15 dB signal fluctuation over range intervals of about 100 yds.

A2 INTENSITY-DECAY LAWS FOR SOUND PROPAGATION IN SHALLOW WATER OF VARIABLE DEPTH

R. N. Denham
J. Acoust Soc. Am. 39, 1170-1173 (1966)

Abstract: Normal-mode theory is applied to the problem of finding the variation of acoustic intensity with range in shallow water of variable depth. A solution of the wave equation is obtained by neglecting the coupling of normal modes produced by the horizontal variation of depth. Relatively simple formulas for the intensity as a function of range are obtained in the case of isovelocity water by averaging the expression for intensity over source and receiver positions and replacing a summation over all the allowed modes by an integration at intermediate ranges. At long ranges, only the first mode is effective and a modified cylindrical spreading law is obtained.

Comment: This is an application of the mathematical approach of A. D. Pierce, J. Acoust. Soc. Am. 37, 19-27 (1965). The mathematical technique is developed and the simple case of a bottom with constant slope is discussed. Averaging the intensity over depth, while providing mathematical simplifications, obscures depth-dependent intensity fluctuations resulting from modal interference which could be significant at intermediate ranges. Fluid bottoms and isovelocity water are assumed.

A3 EFFECTS OF ROUGH BOUNDARIES IN NORMAL-MODE SOUND PROPAGATION

H. P. Bucker and Halcyon E. Morris
J. Acoust. Soc. Am. 40, 252-254(L) (1966)

Abstract: Equations are derived for the calculation of first-order (scattering out of a mode) and second-order (scattering into a mode) scattering corrections to the usual normal-mode solutions. A simplified calculation illustrates the method and shows that, in special cases, sound scattering at the boundaries will cause significant changes in the propagating modes.

Comment: A quasi-empirical approach, from the normal mode point of view, to account for deviations from classical normal mode theory resulting from surface irregularity. The sound field is calculated by combining coherently the intensity of sound in a normal mode and the sound scattered from that mode, and combining incoherently the sound scattered into a mode from others.

A4 ASYMPTOTIC SOLUTION FOR THE SOUND FIELD IN SHALLOW WATER WITH A NEGATIVE VELOCITY GRADIENT

R. N. Denham
J. Acoust. Soc. Am. 45, 365-371 (1969)

Abstract: A solution, valid at high frequencies, for the sound field in shallow water having a negative velocity gradient is obtained by normal-mode theory. Using this solution, relatively simple expressions for the decay of intensity over intermediate and long ranges can be obtained if it is assumed that propagation is basically governed by the mode with phase velocity equal to the surface sound velocity. The transmission loss as a function of range follows a three-halves-power law at intermediate ranges and a cylindrical spreading law at long ranges. In both regions, attenuation due to bottom losses is assumed to be present, and it is shown that the value of this attenuation is approximately the same as that derived by a ray-theory model. In addition, the results of this analysis are in accord with other semiempirical predictions for the transmission loss in shallow water.

Comment: The solution for the sound field obtained for the "limiting mode" (phase speed equal to surface speed of sound) corresponds to a high-frequency approximation so that results should overlap those obtainable from ray theory.

A5 INTENSITY SUMMATION OF MODES AND IMAGES IN SHALLOW-WATER SOUND TRANSMISSION

R. J. Urick
J. Acoust. Soc. Am. 46, 780-788 (1969)

Abstract: The modes and images of wave and ray theories for the propagation of sound in shallow isovelocity water with lossy boundaries have been summed and integrated without regard to phase - that is, by summing and integrating mode and image intensities. This is equivalent to averaging over range and over source and receiver depths. A computer summation of both mode and image models gives the same result: cylindrical spreading for zero loss and a spreading equivalent to a -3/2 power of the range for all finite boundary losses when the ratio of water

depth to wavelength is large. For the lossy case, the transmission loss is found to be proportional to the square root of the reflection coefficient at the boundaries. The same results are shown to be obtained by integrating a continuous distribution of images and modes. The theory leads to a series of curves of transmission anomaly plotted against normalized range that are useful for the prediction of loss in near-isovelocity shallow water, once values for the boundary-loss coefficient and volume-attenuation coefficient have been selected.

Comment: A fine exposition of the practical aspects of theoretical calculation of shallow-water transmission loss which clearly illustrates some interesting relationships between image and mode theories. A good case is made for calculating the average sound field and for intensity summation. The results give a physical feel to the 3/2 law spreading and for the mode stripping phenomenon. It is argued that further advances in the theory will be difficult because of "the present day ignorance" of boundary loss and volume attenuation in shallow water. Particular importance is placed on the measurement of bottom loss at small angles and low frequencies.

A6 WAVE THEORY SOLUTION FOR SOUND PROPAGATION IN A SURFACE DUCT WITH A ROUGH SURFACE (U)

H. P. Bucker
J. Underwater Acous. 19, 13-28 (1969) CONFIDENTIAL

Abstract: (U) Normal mode theory is developed for sound propagation in a surface duct with a rough surface. First-order surface scattering effects are introduced into the solution by incorporating a surface specular reflection coefficient in the formal solution. The second-order effect, an accounting of where the scattered sound energy has gone, is expressed as a combination of wave and ray theory. A connection between ray and mode theory is developed that provides a visualization of the modes in terms of waves that have definite grazing angles, cycle lengths, and so forth. The exponential mode attenuation can then be understood as a combination of specular surface loss plus energy leakage through the thermocline. A comparison is made between calculated values of propagation loss and sea test data involving the SQS-26 sonar. Finally, curves relating mode group velocity to frequency are derived. These curves may be useful in the design of sonar processors as they determine the time spacing of the multipath arrivals.

A7 THEORETICAL SOUND PROPAGATION FOR THE CASE OF A SURFACE DUCT OVERLYING A REFRACTIVE DUCT OF SIMILAR DIMENSIONS (U)

D. F. Gordon
J. Underwater Acous. 19, 29-46 (1969) CONFIDENTIAL

B. NORMAL MODE PROPAGATION - EXPERIMENTAL RESULTS

B1 NORMAL-MODE THEORY APPLIED TO SHORT-RANGE PROPAGATION IN AN UNDERWATER ACOUSTIC SURFACE DUCT

Melvin A. Pedersen and David F. Gordon
J. Acoust. Soc. Am. 37, 105-118 (1965)

Abstract: This paper presents detailed numerical comparisons between propagation losses as calculated by ray theory and by mode theory. Both theories are based on the bilinear surface-duct model. In the image-interference region, the theories give almost identical results, the accuracy of the mode solution being limited at very close ranges by the number of modes treated. As many as 40 modes are considered. Comparison with experimental data at 530 and 1030 cps indicates that the mode theory is definitely superior to ray theory in regions where ray theory predicts shadow zones and caustics. The nature of the mode solution is examined in detail. The manner in which the mode theory produces the image-interference-pattern is controled by the detailed amplitude and phase characteristics of a large number of modes and is not readily interpreted as the interference between a direct and a surface-reflected acoustic path.

B2 EXPERIMENT ON SOUND PROPAGATION IN SHALLOW WATER UNDER ISO-VELOCITY CONDITIONS

A. C. Kibblewhite and R. N. Denham
J. Acoust. Soc. Am. 40, 1337-1344 (1966)

Abstract: An investigation into the long-range propagation of sound in shallow, isovelocity water was carried out using an extensive area of the continental shelf off the west coast of New Zealand. The results obtained showed that a classic example of normal-mode propagation in shallow water was involved. The values of attenuation obtained and the general behavior of the attenuation as a function of frequency are comparable with other shallow-water areas. Other characteristics of the propagation mechanism can be explained in terms of depth variation and layering of the bottom.

Comment: Explosive sound sources were dropped along various directions over a range approximately 100 miles square to the north of South Island. The received signals were investigated over the frequency range 5 Hz to 4.8 kHz. Received signals were curve-fitted by least squares to simple formulae from which effective attenuation constants (frequency and range dependent) were obtained. The results were argued to be in essential agreement with a normal model propagation situation. Sonagrams supported their arguments, along with geological realities of the bottom, but the conclusions rest basically on plausibility arguments.

B3 EPSTEIN NORMAL-MODE MODEL OF A SURFACE DUCT

H. P. Bucker and Halcyon E. Morris
J. Acoust. Soc. Am. 41, 1475-1478 (1967)

Abstract: Equations are given for the normal-mode calculation of the sound field in a surface duct. The velocity-depth profile is represented as

$$1/v^2 = A \operatorname{sech}^2(z/H) - B \tanh(z/H) + D,$$

a form first used by Epstein for calculating the reflection of radio waves from a transition layer. A comparison of calculated and experimental measurements of propagation loss shows good agreement between theory and experiment.

Comment: The authors state that the Epstein profile can be taken as representing a shallow water profile, the SOFAR channel, a submerged surface duct, a transition layer, or a shadow zone, depending upon the values of the various constants in the velocity profile. A comparison between theory and experiment to a range of 10 kyards with data from a NEL test off the California coast reveals excellent agreement. It was necessary to assume the presence of 25 modes to obtain reasonable near-field agreement. The operating frequency was 1030 Hz.

B4 A MODEL OF A WAVEGUIDE LAYER LYING ON A HALF-SPACE WITH A DIFFERENT VELOCITY OF PROPAGATION

Hsiu-Fen, K., and Kuznetsov, V. K.
Sov. Phys.-Acoust. 13, 33-36 (1967)

Abstract: The results are presented from tests on a model of the familiar underwater acoustical problem of sound propagation in shallow water. Visual patterns of the wave field are obtained by using a raster-type record of the amplitude and phase characteristics of the field, wherein it is seen that all the typical features of sound propagation in shallow water are present in the model.

Comment: An analog model of shallow water propagation was constructed which employed an acoustic wave guide. This guide consists of pressure release top and bottom; one end is also pressure release and the water in this region is of depth H_1. A distance L (the water depth being modeled) from this end the water depth is reduced to H_2; and the ratio of H_1 to H_2 determines the index of refraction of the bottom being modeled. Results show for example: the pressure distribution of the first mode in the water and in the bottom, dispersion of the first mode, and for the non-propagating mode the exponential decay in the water layer, the refraction wave in the bottom, and the ordinary refracted wave. While this is an interesting technique for modeling some aspects of layered wave guide propagation, the sophistication of modeling required to bring this into closer analogue with a real shallow water channel remains to be developed.

B5 EXPERIMENT ON SOUND PROPAGATION IN SHALLOW WATER WITH VELOCITY STRUCTURE

A. C. Kibblewhite and R. N. Denham
J. Acoust. Soc. Am. 44, 104-112 (1968)

Abstract: An investigation into the propagation of sound in shallow, isovelocity water was carried out previously using an extensive area of the continental shelf off the west coast of New Zealand. This area has been re-examined when a negative velocity gradient was present in the water layer. The results obtained show that this area provides a classic example of normal-mode propagation in shallow water under conditions of both constant sound velocity and a negative gradient. The values of attenuation obtained are on the whole greater when a negative gradient occurs, but their general behavior with frequency is similar in both cases. In addition, the attenuations are comparable with those obtained in other shallow-water areas and are consistent with the predictions of normal-mode theory.

Comment: The site was to the north of South Island, where the bottom has a thick top layer of unconsolidated sediment. The receivers were on the bottom in

40 fathoms and explosive sources were set to detonate at 60 ft. The authors claim general agreement with normal mode theory with at most only three modes contributing. They state that the deviations are consistent with layering of the sediment and other deviations from the assumptions necessary for the theory. The use of the same ocean area under conditions of constant sound-speed and negative speed gradient, allowing comparisons of the results between the two studies in the same ocean and bottom environment, presents a refreshing example of good research practice.

B6 SOUND FOCUSING AND BEAMING IN THE INTERFERENCE FIELD DUE TO SEVERAL SHALLOW WATER MODES

D. E. Weston
J. Acoust. Soc. Am. 44, 1706-1712 (1968)

Abstract: The formation of sharp rays or beams in Wood's model shallow-water propagation experiments [(V. M. Albers, Ed., Underwater Acoustics (Plenum Press, Inc., New York 1963), pp. 159-192)] is due to an angular selection, and the resulting interference between neighboring high-order modes. Details of the interference mechanism are considered. A given beam should vanish and then re-form with a calculable characteristic distance. The distance is about 4 m in Wood's experiments, and the focusing is clearly visible in his results. These ideas are also applied to a moiré fringe analog, to shallow-water propagation, deep-water propagation, and to transmission of images in fiber optics.

Comment: The occurance of high-intensity beams and their appearance and disappearance at a characteristic distance could be significant for propagation in shallow water if a layered bottom existed which would result in a relatively low reflection loss at one particular angle. The author states that "there is no direct evidence to indicate whether this is an important effect or not." This concept is further refined and shown to have significance in the author's later papers.

B7 SOUND PROPAGATION IN SHALLOW WATER (U)

H. W. Marsh and S. R. Elam
J. Underwater Acoust. 18, 1-23 (1968) CONFIDENTIAL

B8 THREE NEW MODELS FOR SHALLOW WATER PROPAGATION (U)

H. P. Bucker and Halcyon E. Morris
J. Underwater Acoust. 18, 369-377 (1968) CONFIDENTIAL

Abstract: (U) Three new and improved shallow-water, normal-mode models have been developed to represent the shallow-water area encountered on the FASOR I and II cruises. These models include a "linear" gradient velocity profile, an Epstein velocity profile, and a profile with three "linear" gradient segments. In all cases a layered viscoelastic bottom is used. Generally, good agreement is shown between the calculated and experimental measurements of propagation loss on the FASOR stations.

B9 OBSERVATIONS OF FLUCTUATION OF TRANSMITTED SOUND IN SHALLOW WATER

R. J. Urick, G. R. Lund, and D. L. Bradley
J. Acoust. Soc. Am. 45, 683-690 (1969)

Abstract: An 1120-Hz CW sound source was placed on the bottom in 60 ft of water off Fort Lauderdale, Florida. The sound from the source was monitered by a number of hydrophones placed on the bottom about 5000 ft away in the direction parallel to the shore. The received sound was observed to be unsteady, and to exhibit fluctuations of two kinds. One fluctuation had a periodicity of 3 to 4 sec, the same as that of the sea and swell in a 5- to 15-kt wind, and was accompanied by phase-difference fluctuations between hydrophones. The other had a periodicity the same as that of the tides, with fades of 15 dB or more occuring at the times of low water. This tidal variation has been accounted for by both a simplified form of normal mode and by image theory in terms of the interference between the first few modes or rays responsible for the transmission.

Comment: The results obtained in this research are excellent examples of what can be done with experiments using fixed source and receivers.

B10 NORMAL MODE SOLUTIONS FOR TWO AND THREE LAYER VELOCITY PROFILES WITH BOTTOM (U)

C. L. Bartberger and L. L. Ackler
J. Underwater Acoustics 19, 67-92 (1969) CONFIDENTIAL

Abstract: (U) Computer programs have been developed for normal mode solutions of the wave equation based on velocity profiles consisting of two and three layers. The reciprocal of the square of the sound speed in each layer is a linear function of depth. A flat, homogeneous bottom is assumed. Attenuation is included in the bottom, but not elasticity. The solutions are programmed as sums of normal modes, the depth functions being expressed in terms of Airy functions. The eigenvalues are computed by a Newtonian iteration process in the complex plane, the initial estimates being generated by a WKB approximation. The programs have been tested with representative velocity profiles and bottom parameters in both deep and shallow water and comparisons have been made with predictions made from ray theory.

C. RAY THEORY PROPAGATION - THEORY

C1 REFRACTED/REFLECTED RAY TRANSMISSIONS IN A DIVERGENT CHANNEL

Melvin J. Jacobson and John G. Clark
J. Acoust. Soc. Am. 41, 167-176 (1967)

Abstract: Refracted/bottom-reflected ray transmissions in a divergent channel are studied when the sound velocity decreases linearly with depth. Ray geometry is examined in detail and, for a fixed source and receiving point, the number of arrivals, travel time, and spreading loss are found. For the source and receiving point on the

channel bottom, bounds on the acceptable initial inclination angle, travel time, number of bottom reflections, and spreading loss are determined. Further, spreading losses in divergent and horizontal channels are compared. Spreading loss is also examined at all points along a ray emanating from a bottom source. In an example, bottom loss and bottom phase shift are superimposed upon spreading loss and travel-time phase shift, respectively, and the concept of bottom-induced interference is discussed.

C2 COMPARISON OF CURVILINEAR AND LINEAR PROFILE APPROXIMATION IN THE CALCULATION OF UNDERWATER SOUND INTENSITIES BY RAY THEORY

Melvin A. Pedersen and David F. Gordon
J. Acoust. Soc. Am. 41, 419-438 (1967)

Abstract: This paper presents the forms and curve-fitting techniques necessary for the calculation of ray-theory intensities for a curvilinear profile approximation in which continuity of slope as well as velocity is preserved. Using the Epstein profile as a control, this approximation is compared with various approximations that have slope discontinuities. The continuous-slope approximation does not display the artificial effects inherent in approximations with slope discontinuities, such as the introduction of spurious caustics, the omission or real caustics, and the generation of unrealistic regions of low intensity. However, artificial-layering effects in the form of infinite rates of change in intensity appear in the computations for the continuous slope approximation because of discontinuities in the second derivative. The use of a new profile approximation that can preserve continuity of an arbitrary number of derivatives is suggested.

Comment: A good discussion of more realistic ray-tracing methods than are usually found. The authors develop expressions for and analyze cases of ray-paths computed on the basis of linear and curvilinear fittings to an Epstein profile. Various results are compared in detail to the normal mode solution of the Epstein profile. Further refinements to this approach are contained in a later paper (Melvin A. Pederson, J. Acoust. Soc. Am. 43, 619-634 (1968)): The velocity profile is represented in a form allowing matching of second and higher derivatives at the layer interfaces, which reduces the difficulties mentioned above.

C3 SURFACE-REFLECTED/BOTTOM-REFLECTED RAY TRANSMISSION IN A DIVERGENT CHANNEL

Melvin J. Jacobson and J. Thomas Warfield
J. Acoust. Soc. Am. 43, 15-24 (1968)

Abstract: Surface-reflected ray transmissions in a divergent channel are studied when the sound velocity decreases linearly with depth. The sound source and receiving point are located on the bottom. Under certain simplifying assumptions, ray geometry is examined, and conditions are given under which a ray is surface reflected, refracted, or a combination of these. Expressions are developed for travel time and geometrical spreading loss. For an isovelocity medium, initial ray angle, travel time, and spreading loss of individual arrivals are examined as functions of bottom angle. These quantities are shown to be greater for a divergent channel than for a horizontal channel. Assuming a CW source and Rayleigh reflection theory, the total field at a receiving point is determined. It is found that the variation in intensity values decreases with increasing bottom divergence.

C4 RAY TRANSMISSION IN AN UNDERWATER ACOUSTIC DUCT WITH A PSEUDO-RANDOM BOTTOM

A. D. Seifer and M. J. Jacobson
J. Acoust. Soc. Am. 43, 1395-1403 (1968)

Abstract: The principles of geometrical optics are applied to a study of ray acoustics in an isovelocity sound channel bounded by a lossy, pseudorandom (facet) bottom below and a free, planar surface above. A point source and receiving point are fixed and in a plane normal to the bottom so that all rays between them are coplanar. At each point of ray reflection, the bottom is assumed locally linear with sufficient length so that almost all of the reflected radiation takes the locally specular direction. At a point of ray reflection, the bottom is assumed to have a small random slope about a zero mean and a small random depth deviation about a constant mean value. Effects of boundary loss and phase shift, geometrical spreading loss, and travel time are included; and bottom-reflected arrivals are shown to be almost constant in amplitude but incoherent in phase. Multipath interference of all arrivals is treated by a random-walk theory. Graphs are presented giving the mean and standard deviations of the sound-field intensity for various source and receiving point geometries.

Comment: The development is restricted to a one-dimensional bottom roughness, so that scattering out of the insonified region, resulting from facets whose normals do not lie in the (vertical) plane including source and receiver, is not considered.

C5 RAY THEORY OF THE GENERAL EPSTEIN PROFILE

Melvin A. Pedersen and DeWayne White
J. Acoust. Soc. Am. 44, 765-786 (1968)

Abstract: This paper presents the detailed mathematical properties and the ray-theory ranges, intensities, and travel times of the five-parameter Epstein profile with the parameters assuming all values capable of producing real velocities. Although examples represent the underwater-sound situation, results apply to any ray theory. The wealth of profile forms produces special cases requiring intricate analysis, but leads to more complete understanding of field theory. Analyses of rays that become horizontal at velocity extrema show little dependence on profile symmetry for the case of a velocity maximum, but a marked dependence for the case of a velocity minimum. This last is a point of significance apparently neglected in the literature covering ray-theory channels. Very steep, channeled rays, which become horizontal at very high (infinite) velocities, are shown to have a loop range $\pi C(dZ/dC)$, where the velocity-slope product is evaluated as a limit at the infinite velocity. This expression, valid for profiles other than the Epstein profile, was suggested by examination of the hyperbolic cosine profile, which is a degenerate case of the Epstein profile.

C6 RAY TRANSMISSIONS IN AN UNDERWATER ACOUSTIC DUCT WITH A BOTTOM HAVING CURVATURE

A. D. Seifer and M. J. Jacobson
J. Acoust. Soc. Am. 44, 1103-1114 (1968)

Abstract: A general spreading-loss equation is developed for specularly reflected rays in a medium whose sound velocity varies with depth and whose bottom has one-dimensional roughness with curvature. When the sound velocity is constant, curvatures is found to be most important when the grazing angle is small. The spreading loss is given in terms of a determinant, and the relative importance of bottom depth deviation, slope, and curvature are compared when these parameters are small. Bottom loss is then included, and the amplitudes of ray arrivals at a fixed receiving point are found. The bottom parameters are taken to be random, and the variances of the amplitude in decibels of each arrival and of the total field are determined. In an example, Rayleigh's reflection theory is employed, and the source and receiving points are placed on the bottom. It is found that curvature can cause significant amplitude variation, which might otherwise be negligible if curvature were neglected. Finally, the spreading loss is determined for a layered medium bounded by a bottom with curvature.

C7 CALCULATION OF HORIZONTAL RANGES AND SOUND INTENSITIES BY USE OF NUMERICAL INTEGRATION TECHNIQUES

Max K. Miller
J. Acoust. Soc. Am. 44, 1690-1698 (1968)

Abstract: The purpose of this paper is to point out some advantages in the calculation of horizontal ranges, travel times, and sound intensities by means of numerical techniques that seem to have been overlooked in the past. The integrals for horizontal range, travel time, and sound intensity are evaluated directly for reflected rays, while appropriate modifications are made for refracted rays. This approach to the problem of calculating sound intensities is discussed, and two numerical examples are given that point out the accuracy and advantages of the method.

Comment: Sound speed is assumed to be a function of depth only, specified at discrete points. Difficulties still remain for refracted rays which become horizontal. Comparisons are made with an exact solution to the Epstein profile. The author concludes " . . . It is intended to be used both as a research tool and as an automated process (reflection cases) for use on large numbers of data. It should be especially useful for calculation of horizontal ranges for either case."

D. RAY THEORY PROPAGATION - EXPERIMENTAL RESULTS

D1 PRACTICAL MODEL OF SHALLOW-WATER ACOUSTIC PROPAGATION

J. D. Macpherson and M. J. Daintith
J. Acoust. Soc. Am. 41, 850-854 (1967)

Abstract: An approximate model of shallow-water propagation based on ray theory and a simple representation of the medium is presented. Simple equations are derived, which taken into consideration the water depth, bottom slope, reflection losses and velocity gradients in the water. Two practical illustrations of propagation on Sable Bank in isovelocity and negative velocity-gradient conditions are given. The conclusion is reached that, under isovelocity conditions, the reflection loss at the surface is controlling propagation loss, whereas under negative velocity-gradient conditions the surface is unimportant and the bottom reflection loss dominates. Comparison of surface reflection loss is made with other measurements.

Comment: Assumptions,- water depth greater than ten acoustic wavelengths; intensity from different acoustic arrivals are added incoherently; grazing angle is small; loss per reflection off the bottom in dB is proportional to the grazing angle. The theory allows for sloping bottom. Comparisons of the theory with experimental data taken on Sable Bank are quite good, but this is in part due to some use of adjustable parameters for the reflections from the bottom. The theory does not apply when the gradient is positive, when there are large fluctuations in the velocity gradient with range, or when there are very weak negative gradients over a strongly reflecting bottom.

D2 SHALLOW-WATER PROPAGATION UNDER DOWNWARD-REFRACTION CONDITIONS

Bernard F. Cole and Eugene M. Podeszwa
J. Acoust. Soc. Am. 41, 1479-1484 (1967)

Abstract: The important features of shallow-water sound transmission under downward-refraction conditions are interpreted in terms of ray theory and are discussed relative to some specific 30-f (fathom) propagation-loss results. The propagation results are shown to depend directly upon the velocity profile and the bottom loss. A bottom-loss value of 1.3 dB per bounce was inferred from the measurements and is shown to compare favorably with theoretical values computed from bottom-impedance information. Observed pulse shapes are then compared with theoretical pulse shapes synthesized from the combined ray and bottom-loss models. In addition, the computed propagation-loss values for the various paths are presented as a function of source angle in order to illustrate the vertical directivity introduced by the environment. Finally, the effect of this vertical directivity on shallow-water propagation measurements is demonstrated by comparing propagation-loss results for directional and explosive sources.

Comment: Data were taken at 3.5 kHz under downward refracting conditions over a sand bottom. The bottom grazing angle was 10° - 12° and the skip distance was about 1000 yd. Source had a 20° vertical beamwidth. After volume absorption and system vertical directivity were taken into account, the experimental results were fitted by adjusting the bottom loss. Results allow the inference that effects due to bottom roughness were negligible. Curves for propagation loss as a function of receiver depth at two ranges (6 and 10 kyd) are presented, showing the effect of velocity profile on propagation loss. The following two comments are of interest: "...ray theory provides an excellent base for the interpretation of the important features of shallow-water sound transmission under downward-refraction conditions" "...environmentally induced vertical directivity makes the propagation of sound in shallow water under downward-refraction conditions relatively insensitive to the vertical directivity of the source."

D3 PREDICTING SHALLOW-WATER TRANSMISSION LOSS

Bernard F. Cole
J. Acoust. Soc. Am. 42, 903-904(L) (1967)

Abstract: The applicability of ray theory for predicting shallow-water propagation loss at sonar frequencies is discussed.

Comment: The author compares the Marsh-Schulkin model predictions with some experimental data, and with a "complicated model that combined ray theory and bottom-impedance considerations." The values for skip distance and mean boundary loss are quite different (1.2 kyd and 1.3 dB/bounce for Cole as opposed to 4.75 kyd and 3.6 dB/bounce for Marsh-Schulkin). The values for Cole's model were obtained by fitting the model to the experiment; the values for the Marsh-Schulkin model, although in very poor agreement, produced transmission loss predictions in agreement with the observed values. The author states "It must be concluded, in view of the above result, that the only justification for employing detailed ray models in predicting (as opposed to interpreting) shallow-water transmission losses under downward-refraction conditions is to obtain more physical harmony rather than more numerical consistency. Moreover, considering the detailed knowledge of the environment that is required, it is difficult to employ ray models for interpreting measured shallow-water transmission losses, and it is nearly impossible to use ray models to predict such losses in view of the present state of the art."

D4 A PREDICTION MODEL FOR SHALLOW WATER SOUND TRANSMISSION

R. J. Urick
Naval Ordnance Laboratory, NOLTR 67-12 (1967)

Abstract: For predicting the transmission loss to long ranges in shallow water with downward refraction, when only a limited knowledge about the bottom is available, a theoretical model is derived leading to a particularly simple expression for the loss in terms of the water depth, velocity gradient and bottom reflection loss at small grazing angles. This latter quantity, for which no measurements are extant, is approximated through computed curves of reflection loss at the boundary of a semi-infinite absorptive fluid. A test of the model is provided by two sets of field data. One consists of recent measurements by NEL at 1.5 kHz, along with core sample measurement of bottom density and sound velocity, in several Pacific Ocean areas. The other comprises a hitherto-unpublished transmission survey at 12 kHz made in 1944 by WHOI around our East and Gulf coasts. For this mass of data, the only information about the bottom is contained in words like "mud" and "sand". Reasonable agreement with both sets of data is found. The model appear to be useful for making approximate predictions of transmission loss in shallow water.

D5 SHALLOW WATER SOUND TRANSMISSION IN THE BALTIC SEA AND OFF THE COAST OF SPAIN

Samuel W. Marshall and Joel G. Hanse, Colorado State University
Technical Report No. N 00014-67-A-0299-0002-1 (1969)

Abstract: Two underwater sound experiments were conducted, one in the Baltic Sea and the other in the Atlantic Ocean off the coast of Spain. The data of these experiments were analyzed to determine such properties of the bottom as the layer number, depth and sound velocity. A review of two mathematical calculations used in the data analysis is also given. The Baltic Sea data indicated that the bottom was homogeneous. It also indicated that the water layer could be considered as a perfect waveguide. The Atlantic data indicated that the bottom was a finite layer over a semi-infinite homogeneous high velocity sub-bottom.

E. BOTTOM ACOUSTICS

E1 REFLECTION OF LOW-FREQUENCY SONAR SIGNALS FROM A SMOOTH OCEAN BOTTOM

H. P. Bucker, J. A. Whitney, G. S. Yee, and R. R. Gardner
J. Acoust. Soc. Am. 37, 1037-1051 (1965)

Abstract: Measurements of the bottom-reflection losses for a low-frequency sonar signal (0.7-3.0 kc/sec) are reported for two areas off the California coast and for a third area in the Bering Sea. At all three areas, the bottom losses were large at small grazing angles. Comparisons are made between the measured values of bottom loss and those calculated for a plane sound wave reflecting from a layered model of the ocean sediments. The sediment model consists of a number of absorbing solid layers. Reasonable agreement is shown between the experimental and calculated values of bottom loss.

Comment: One area is in 200 fathom water. The others are at 2000 fathoms.

E2 STUDIES OF OBSERVED AND PREDICTED VALUES OF BOTTOM REFLECTIVITY AS A FUNCTION OF INCIDENT ANGLE

R. R. Menotti, S. R. Santaniello, and W. R. Schumacher
J. Acoust. Soc. Am. 38, 707-714 (1965)

Abstract: A theoretical model of the ocean bottom has been developed for studies of bottom reflectivity. The model consists of many absorbing liquid, plane parallel layers over one semiinfinite solid. Using this model, computations of reflection coefficients as a function of incident angle were performed. Measurements of the acoustic reflectivity of an area of Atlantic Ocean bottom, using a deep streamed projector and two deep-fixed receiving hydrophones, were made at a frequency of 1000 cps and for two pulse lengths. The experimentally derived reflection coefficients are analyzed on the basis of pulse length, for each hydrophone, and comparison is made with the predicted coefficients obtained from the theoretical model.

Comment: Experimental results were restricted to angles of incidence between 25° - 85° so that grazing angles in excess of 5° were studied. The authors claim good agreement between experiment and theory for grazing angles less than 30°. Bottom roughness was not considered.

E3 ACOUSTIC PROPERTIES OF SEDIMENTS

Loyd D. Hampton
J. Acoust. Soc. Am. 42, 882-890 (1967)

Abstract: This is a summary of an experimental study to measure the acoustic properties of water-saturated sediments. The sediments used where laboratory prepared to allow control of physical parameters (such as grain size, volume concentration, compressibility, etc.) and to approximate natural sediments. Acoustic velocity and attenuation in the sediments were measured by means of two probes inserted in the sediments, and at low frequencies by means of a specially constructed rigid-wall standing-wave tube. The data presented show the frequency dependence of attenuation and velocity in the laboratory-prepared sediments and the change in this frequency dependence with changes in physical parameters of the sediments. Sediments composed of pure kaolinite, or kaolinite and sand up to 15% (by weight) show an $f^{1.37}$ frequency dependence of attenuation. Sediments with greater than 30% sand (by weight), including pure sand, exhibit and $f^{0.5}$ frequency dependence of attenuation. The measured velocity dispersion is approximately 2% over the range 4-200 kHz. Velocity increases with frequency. All measurements reported are for sediments free of entrapped gas.

E4 PROCEEDINGS OF USL SEMINAR ON BOTTOM REFLECTION

Navy Underwater Sound Laboratory, Report No. 825
(1967) CONFIDENTIAL

Abstract: (U) An in-house seminar was held at the Underwater Sound Laboratory on 28 and 29 March 1967, to review laboratory sponsored programs that are concerned with the reflection of underwater sound off the ocean bottom. The papers presented reflect the laboratory's direct effort in the pursuit of problems relating to the performance of surveillance and communication systems that employ the bottom reflection of acoustic signals. These proceedings document recent developments in theoretical studies, experimental research programs, and systems research and development programs relating to the acoustic and physical properties of the ocean bottom.

Comment: The successes and failures enumerated in this document relative to attempts to measure, predict, and correlate single reflection bottom losses as a function of grazing angle, frequency, bottom core samples, nature of coded signals, acoustic impedance of bottom, multilayers in bottom, etc. should offer guidance in organizing a similar program to investigate the influence of bottom reflections in shallow water propagation of sound.

E5 THE NORMALLY-INCIDENT REFLECTIVITY OF THE SEA FLOOR AT 12 kc AND ITS CORRELATION WITH PHYSICAL AND GEOLOGICAL PROPERTIES OF NATURALLY-OCCURRING SEDIMENTS

Breslau, L. R., Woods Hole Oceanographic Inst., Mass.
Ref. 67-16 (1967)

Abstract: The objective of this investigation was to measure bottom loss in normal incidence reflection of pulses of 12 kcps sound and to study its geological significance. A semi-automatic instrument system was developed capable of making continuous measurements of the peak pressure and the time integral of the square of the pressure of the sea-floor echo from a vessel underway. Observations were taken in both deep and shallow water in the Western North Atlantic.

E6 SOUND SPEED AND ATTENUATION, FROM 15 TO 1500 kHz, MEASURED IN NATURAL SEA-FLOOR SEDIMENTS

E. G. McLeroy and A. DeLoach
J. Acoust. Soc. Am. 44, 1148-1150(L) (1968)

Abstract: Laboratory measurements of the sound speed and attenuation in natural sea-floor sediments have shown that the speed ranges from 0.997 to 1.19 that in sea water, and that the attenuation is directly proportional to frequency over the range of measurements (15-1500 kHz). Values of the attenuation coefficient range from 0.7 dB/ft at 15 kHz for silty-clay sediment to 75 dB/ft at 1500 kHz for sand.

E7 INVESTIGATIONS OF SEDIMENT PROPERTIES IN SONAR BOTTOM REFLECTIVITY STUDIES

James J. Gallagher and Vito A. Nacci, Navy Underwater Sound Lab
USL Report No. 944 (1968)

Abstract: The objective of the investigation of sediment properties in acoustic bottom loss studies is to develop a capability to predict acoustic energy loss in various types of ocean depositional areas. This capability is being developed primarily by laboratory experiments on sediment samples and by model studies, utilizing laboratory-derived values of sediment properties. The data presented are the result of analyses performed on five cores taken from the Tongue of the Ocean, in an area less than two miles in diameter. The elastic properties of these soils were investigated by means of longitudinal and torsional wave vibration apparatus, confined compression tests, and static triaxial shear tests. The results of a pilot study indicate that the stress strain relationship for static and dynamic loading of confined or unconfined homogeneous soil samples is considerably influenced by the void ratio or confining pressures. This results in a general trend of increasing modulus with depth. However, variations occurring in the corresponding vertical sound velocity profiles indicate that other parameters are influencing the sound velocity structure. Therefore, the object of primary concern is to determine the relationships between the structural and behavioral properties of the soil aggregate and its elastic moduli.

F. BOTTOM SCATTERING AND REVERBERATION

F1 SHALLOW WATER REVERBERATION

Macpherson, J. D. and Harris, J. H.
J. Underwater Acoust. 15, 361-370 (1965) CONFIDENTIAL

F2 MEASUREMENT OF THE ACOUSTIC SCATTERING COEFFICIENT OF THE OCEAN BOTTOM BY MEANS OF A SHORT PULSE

Zhitnovskii, Yu Yu
Sov. Phys. -Acoust. 12, 328-329 (1967)

Comment: A brief derivation of an equation to be used in measuring the acoustic scattering coefficient of the bottom. No experimental data are presented.

F3 REFLECTION AND SCATTERING OF SOUND FROM THE OCEAN BOTTOM (REVIEW)

Zitnovskii, Yu Yu and Lysanov, Yu P.
Sov. Phys. -Acoust. 13, 1-13 (1967)

Comment: This review article contains a considerable amount of experimental data on bottom reflection at normal incidence as well as the dependence of bottom reflection on frequency, angle of incidence, and nature of the bottom. It also contains similar experimental data on the scattering of sound from the bottom.

F4 SOUND REFLECTION FROM A LOW-VELOCITY BOTTOM

Robert S. Winokur and Joyce C. Bohn
J. Acous. Soc. Am. 44, 1130-1138 (1968)

Abstract: Measurements of ocean-bottom reflectivity were made using explosive sound sources and bottom reflection coefficients determined for grazing angles between 2° and 85°. Theoretical reflection coefficients were computed using a multilayered model of the ocean bottom, in which the lowermost layer is considered to be semi-infinite and solid. The layers are assumed to have plane-parallel interfaces and to be absorbing. Sediment sound-speed measurements made on cores collected in the area, and used in the theoretical computations, indicate the bottom in this region to be a low-velocity sediment interspersed with thin high-velocity layers. Oscillograph records made of the bottom- reflected signals show a phase reversal, with respect to the incident wave at the angles theoretically predicted. Comparisons of theoretical and measured reflection coefficients are made at 1, 2, and 4 kHz, and, in general, the over-all agreement is good. An unusual increase in measured reflection coefficient with frequency is observed at the angle of intromission and can, in part, be explained by the presence of subbottom reflectors.

Comment: The data were collected in 2400-f water in the Yucatan Basin of the Caribbean Sea.

F5 BOTTOM BACKSCATTERING NEAR GRAZING INCIDENCE IN SHALLOW WATER

How-Kin Wong and W. D. Chesterman
J. Acoust. Soc. Am. 44, 1713-1718 (1968)

Abstract: Data obtained from measurements of the backscattering of 48-kc sound from the sea bottom at 12 locations in the inshore waters of Hong Kong show that the bottom backscattering strength increases by some 25 dB as the textural grade changes from clay through silt and sand to rock. For the range of grazing angles from 0.5° to 6°, the backscattering strength is constant. The experimental results also show that a knowledge of the percentage of sand and the effective bottom roughness is particularly useful for the estimation of bottom reverberation levels. The attenuation coefficient of 48-kc/sec sound at 20°C in the subtropical waters of Hong Kong is found to range from 9.4 to 12.8 dB/kyd, depending upon local conditions. The average value obtained is 11.2 dB/kyd.

F6 PREDICTION OF BOTTOM REFLECTION LOSS FROM A SINGLE SEDIMENT PARAMETER (U)

R. J. Urick and D. L. Bradly
Naval Ordnance Laboratory, NOLTR 68-127 (1968)

G. SURFACE SCATTERING AND REVERBERATION

G1 COHERENT REFLECTION OF SOUND FROM AN OCEAN SURFACE LAYER CONTAINING RESONANCE SCATTERERS

V. P. Glotov and Y. P. Lysanov
Sov. Phys. - Acoust. 10, 360-364 (1965)

Abstract: The reflection coefficient is calculated for a plane wave reflected from a surface layer of the ocean containing resonance scatterers whose sizes are small in comparison with the effective wavelength (air bubbles) and which occur beneath a rough (wavy) ocean surface due to the wind. It is shown that under certain conditions the uneven surface of the ocean may be "screened" by a layer of bubbles. The article analyzes the various mechanisms for the onset of this "screening" effect. A numerical calculation is made of the reflection coefficient as a function of the layer thickness and bubble concentration therein.

Comment: It is assumed that the bubbles present beneath the sea surface are distributed uniformly, on the average, over the layer thickness.

G2 MASKING OF SURFACE REVERBERATION BY VOLUME REVERBERATION

Robert L. Shaffer
J. Acoust. Soc. Am. 39, 408-411(L) (1966)

Abstract: Measurements of the backscattering of 4-kcps sound from the surface of the sea at a grazing angle of 5° and a wind speed ranging from less than 5 kt (knots) to greater than 35 kt were made off Bermuda. It was assumed that surface backscattering is wind-speed dependent; volume backscattering, on the other hand,

was assumed not to be wind-speed dependent in order to distinguish between surface reverberation and volume reverberation. It was observed that volume reverberation prevails at the lower wind speeds (smooth sea surface), whereas surface reverberation prevails at the higher wind speeds (moderate to rough sea surface). The surface scattering strength data compared favorably with results previously reported in the literature.

Comment: A rather inconclusive study, with too little experimental evidence available to reach any definite conclusions. The general comments are useful, however, and the data seem consistent with the assumptions within fair accuracy.

G3 SEA-SURFACE ROUGHNESS AND ACOUSTIC REVERBERATION -- AN OPERATIONAL MODEL

J. J. Martin
J. Acoust. Soc. Am. 40, 697-710 (1966)

Abstract: Underwater acoustic reverberation from the sea surface appears to be a combination of specular reflections and diffuse scattering, which may include, on an experimental basis, the effects of subsurface volume reverberation. This paper (1) separates these contributions as a function of incidence angle, radiation wavenumber (frequency), and sea-surface wind-speed; (2) shows the fundamental relationship between specular reflections and diffuse scattering; (3) developes a tentative spectrum of roughness at large wavenumbers for a developing sea surface; (4) points out various radiation-wavenumber, incidence-angle and wind-speed regimes associated with sea-surface returns; and (5) presents a correlation formula for acoustic reverberation from a sea surface, which is applicable as well to forward scattering of both sound and radar waves. The results of the paper are familiar in the sense that no new mechanism for reverberation is invoked and novel in the sense that the familiar mechanisms are used to interpret acoustic, turbulence, and hydrodynamic data in a manner that predicts sea-surface acoustic reverberation in a physically consistent way.

Comment: The author states: "The structure of the model described here rests essentially upon the knowledge of the sea-surface wave number spectral densities of elevation, slope, and curvature at wavenumbers of the order of the incident radiation wavenumber. Given these spectral densities, the counting of reflecting facets as a prelude to estimating specularly reflected energy is a tractable mathematical problem, but estimating the reflection coefficients of these facets of unknown size and curvature is formidable."

G4 INFLUENCE OF A NONUNIFORM DISTRIBUTION OF AIR BUBBLES ON THE REFLECTION OF SOUND FROM THE SURFACE LAYER OF THE OCEAN

V. P. Glotov and Y. P. Lysanov
Sov. Phys.-Acoust. 11, 421-423 (1966)

Comment: This is an extension of the previous work of the authors (Sov. Phys.-Acoust. 10, 360-364 (1965)) to take into account a nonuniform distribution of bubbles in the region just beneath the sea surface. Here, it is assumed that the sea surface is flat and that the mean concentration of bubbles decreases linearly with depth until a depth H below which the concentration is zero.

G5 BOUNDARY SCATTERING EFFECTS IN UNDERWATER SOUND PROPAGATION

H. W. Marsh and R. H. Mellen
Radio Science 1, 339-346 (1966)

Abstract: Signal scattering by rough boundaries is a phenomenon common to both radio and underwater sound propagation. A theory, supported by experimental evidence, is presented relating the angular scattering spectrum and the boundary roughness spectrum by first-order diffraction. Accordingly, the Doppler velocity for surface wave scatter is the phase velocity corresponding to wavelength resonance. Both radar and sonar backscatter measurements, however, show random velocity distributions except at long wavelengths, indicating that the wind-driven sea surface is predominantly turbulent. Measurements of temporal coherence of forward-scattered signal are also presented. In this case, the theoretical Doppler spectrum is dominated by motions of the longest waves.

Comment: The authors state: "Ultimately, there are limits set by the random fluctuations and inhomogeneities of the medium and the resulting unpredictable distortion of the signal. Of the many features of the ocean environment that contribute to acoustic variability, the surface and the bottom boundaries are particularly important. Viewed in this manner, the ocean resembles a thin layer with complex and changing properties. The effect of environmental factors depends strongly on their time and length scales, relative to frequencies and wavelengths of underwater sound."

G6 THEORETICAL STUDIES ON THE SCATTERING OF ACOUSTIC WAVES FROM A ROUGH SURFACE

C. W. Horton, Sr., and T. G. Muir
J. Acoust. Soc. Am. 41, 627-634 (1967)

Abstract: The theory for the scattering of acoustic waves from a stochastic surface that was developed by Eckart is applied to surfaces with various statistical properties. Specific formulas for the scattering coefficient, both for the low- and the high-frequency cases, are computed for isotropically rough surface whose autocovariance functions are exponential, Gaussian, and sinusoidal. The low-frequency scattering is examined for other autocovariance functions having interesting properties. The relative effect of the size of the insonified region and the area of coherent surface relief is considered in two examples.

G7 MODEL STUDIES ON THE SCATTERING OF ACOUSTIC WAVES FROM A ROUGH SURFACE

C. W. Horton, Sr., S. K. Mitchell, and G. R. Barnard
J. Acoust. Soc. Am. 41, 635-643 (1967)

Abstract: A rough surface 32 in. by 32 in. in size was made of a pressure-release material. The relief of this surface was approximately Gaussian with a standard deviation of 0.6 wavelengths at 100 kHz. Experimental measurements were made of the scattering of acoustic waves in the plane of incidence at a frequency of 100 kHz for grazing angles of incidence of 20°, 40°, 45°, and 90°.

The grazing angle of reflection was varied from 6° to 116° in each case. One set of measurements was made at 200 kHz. The statistical parameters of the surface were computed and these values were used in the theoretical formulas developed by Eckhart. Close agreement between experiment and theory was obtained for all measurements except at an incidence grazing angle of 30°. In this case, it was necessary to introduce a correction to the mean-square surface relief in order to correct for the shadowing effect. Theoretical results are presented for the scattering coefficient for directions not in the plane of incidence.

Comment: The authors comment that the theoretical analysis of Kuo (E.Y.T. Kuo, J. Acoust. Soc. Am. 36, 2135-2142 (1964)) suggests that reflection loss can be represented by a product of two quantities, one determined by surface shape and the other by bottom composition; this allows results based on pressure-release rough surfaces to be applied to real bottoms. (The authors express plans to test this theoretical prediction.) Results are in fair agreement with theory, although this required modifications in boundary conditions at the scattering surface for all cases and in parameter characterizing surface roughness at the smallest grazing angle.

G8 SOUND SCATTERING BY THE SURFACE OF THE OCEAN AND BY SURFACE SCATTERING LAYERS

I. B. Andreeva and E. G. Kharat'yan
Sov. Phys.-Acoust. 12, 350-354 (1967)

Abstract: The results are presented from an investigation of sound scattering in a surface layer of the ocean. The sound source was an underwater explosion. The absolute values of the effective back-scattering coefficient of the surface were measured and their dependence on the frequency and grazing angle found in the intervals 1-40 kc and 10-60°. It is shown that at grazing angles < 30° and frequencies of 3-10 kc the scattered field is determined primarily by volume scattering, by sound-scattering layers in particular, and not by irregularities of the water-air interface.

Comment: The authors feel that at frequencies above 10 kc surface irregularities dominate; generally, for steep incidence of the sound rays at the surface, surface irregularities form the dominant mechanism of scattering, while at smaller grazing angles (and particularly between 3-10 kc) surface irregularities becomes of lesser importance compared to biological and bubble scattering contributions.

G9 SOUND SCATTERING INTO THE SHADOW ZONE BELOW AN ISOVELOCITY LAYER

Britt J. Schweitzer
J. Acoust. Soc. Am. 44, 525-530 (1968)

Abstract: A mathematical model is developed to describe sound propagation into the shadow zone below an isothermal layer by means of scattering from a rough surface. The model incorporates a formula that describes the propagation losses within the duct to points from which the sound is scattered. The Beckmann theory is then used to estimate the scattered intensities at the various angles that correspond to ray paths leading from the surface to a point in the shadow zone.

Reasonable agreement is found between the theoretical results and observations made at 5 kHz in a moderately rough sea. The theory indicates that most of the scattering occurs in a narrow region of the surface between 200 and 1200 yd from the point of observation in the shadow zone.

Comment: The intensity in the shadow zone is shown to be due to scattering from a small area of surface confined to a narrow region on the line between source and receiver. This region is of small extension in range. Travel times are not very different as no pulse distortion was observed.

G10 NORMAL-MODE REVERBERATION IN CHANNELS OR DUCTS

H. P. Bucker and Halcyon E. Morris
J. Acoust. Soc. Am. 44, 827-828 (L) (1968)

Abstract: Equations are derived for calculation of sonar reverberation in terms of quantities used in a normal-mode propagation calculation. The equations are suitable for moderate to long ranges and for both surface ducts and shallow-water channels.

Comment: In shallow water, experiments show that the echo-to-reverberation ratio tends to remain constant with range. The theory patches together mode and ray theory by use of a Lambert's law-type surface-scattering relationship. Results are compared to data for a two isovelocity shallow-water channel with a visco-elastic bottom. (The frequency was not specified.) Shown are the theoretical contributions of: sea-surface (small), near surface (1-ft deep layer of scatters with a coefficient of -67 dB/yd), and bottom (main source of reverberation). The bottom scattering coefficient had to be adjusted by -2dB from the previously reported value.

H. SHALLOW WATER AMBIENT NOISE

H1 AMBIENT NOISE AND PROPAGATION MEASUREMENTS IN THE BERING SEA (U)

B. M. Buck and R. P. Brumbach, GM Defense Research Lab.
(TR 65-77) (1965) CONFIDENTIAL

H2 UNUSUAL LOW-FREQUENCY SIGNALS OBSERVED IN NEW ZEALAND WATERS

A. C. Kibblewhite, R. N. Denham, and D. J. Barnes
J. Acoust. Soc. Am. 41, 644-655 (1967)

Abstract: From time to time, strong underwater transient signals have been detected in New Zealand waters. Much of this activity appears to be biological in origin, and some of it is obviously similar to underwater signals observed in other parts of the world, other components are by no means so well known and provide further interesting examples of pulses in which the energy is confined to a narrow band of frequencies around 20 cps. These pulses are described.

Comment: A largely descriptive article dealing with biological (assumed) sources of low frequency sound, chiefly ascribed to whales. Observations are for both deep and shallow water, and are of interest in describing some of the low frequency biologically originated sound which can be found in ambient noise.

H3 FURTHER MEASUREMENTS ON THE EFFECT OF ICE COVER ON SHALLOW-WATER AMBIENT SEA NOISE

F. A. Payne
J. Acoust. Soc. Am. 41, 1374-1376(L) (1967)

Abstract: Shallow-water ambient-noise measurements have been made under open water and ice cover conditions at Prince Edward Island. Through the use of improved equipment, measurements were made that covered a greater range in frequency (3-3200 cps) and noise levels than previously reported for this area.

Comment: This is an extension of work reported by the author (J. Acoust. Soc. Am., 36, 1943-1947 (1964)) undertaken in the area of North Rustico, Prince Edward Island. Spectral levels for ice cover are significently different than for open water in the range 10 - 1000 Hz in shape of the profile as a function of frequency. The under-ice spectra suggest that below 20 Hz noise is due to turbulent pressure fluctuations in a body of water moving with a mean speed of 0.25 kt. The wind-dependent component of the noise spectrum was shown to be proportional to the log of the wind speed, with a frequency dependent proportionality constant equal to 1.07. Below 40 Hz, ambient-noise level fluctuated widely.

H4 AMBIENT-NOISE LEVELS IN SELECTED SHALLOW WATER OFF MIAMI, FLORIDA

M. Ward Widener
J. Acoust. Soc. Am. 42, 904-905(L) (1967)

Abstract: Noise-level measurements have been made in shallow water off Miami, Florida. Areas containing snapping shrimp have been calibrated for noise levels in excess of 30 dB over Sea State 1 up to 50 kHz. Spectral components were observed to 150 kHz with lower frequencies extending down to 4 kHz.

Comment: Measurements were made during the week of 17 October 1966, over a time interval from 1 h before sunrise to 2 h after sunset. The conclusion states "Serious limitations on the performance of sonar equipment can be expected in any coastal waters favorable to habitation by snapping shrimp."

H5 SHALLOW WATER AMBIENT NOISE LEVELS IN THE TONGUE OF THE OCEAN, BAHAMAS, FALL OF 1965 AND SUMMER OF 1966

J. S. Woodson and W. J. Reaves
Naval Oceanographic Office, Informal Report No. IR 69-57 (1969)

I. SIGNAL DISTORTION IN SHALLOW WATER

I1 UNDERWATER SOUND PROPAGATION IN THE STRAITS OF FLORIDA

J. C. Steinberg and T. G. Birdsall
J. Acous. Soc. Am. 39, 301-315 (1966)

Abstract: In a fixed-system study of relationships between variations in underwater sound transmission across the Straits of Florida and variations in environmental factors, an unexpected degree of phase stability was observed. The phase of the received wave, referenced to the phase of the transmitted wave, varies less than 100° during intervals of 1/2-1h. Intervals of 1-4h occured in which the phase varied less than 360°. In other intervals, the phase drifted in positive or negative directions at maximum rates of 5°-15°/min. The over-all behavior had a pronounced diurnal period. The observations were made during a 4-day continuous test employing 420-Hz CW (Continuous Wave) transmission. Results for individual arrivals by different paths, obtained in subsequent transmission employing pseudo-random sequences, were consistent with the CW observations.

I2 RECENT RESULTS FROM STRAITS OF FLORIDA UNDERWATER-SOUND-PROPAGATION STUDY

J. G. Clark, R. Dann and J. R. Yarnall
J. Acoust. Soc. Am. 40, 1195-1197(L) (1966)

Abstract: The phase-versus-time patterns of acoustic signals transmitted across the Straits of Florida in March 1966 show close similarities with corresponding patterns presented recently be Steinberg and Birdsall (J. C. Steinberg and T. G. Birdsall, J. Acoust. Soc. Am. 39, 301-315 (1966)), which were obtained 14 months earlier. Both diurnal and tidal periodicities appear in the patterns, and the phases of the tide were approximately the same during the two intervals. The phase patterns at recently installed hydrophones located two to three miles from the sound source also show the characteristic periodicities observed at locations across the Straits. All data obtained from this program thus far lead to the conclusion that signal phase, in sharp contrast to amplitude, is basically very stable, and that many of the fluctuations that do occur may be associated with large-scale environmental events.

I3 OPTIMUM WAVEFORMS FOR CORRELATION DETECTION IN THE SONAR ENVIRONMENT: NOISE-LIMITED CONDITIONS

Thomas G. Kincaid
J. Acoust. Soc. Am. 43, 258-268 (1968)

Abstract: Sonar systems currently in use and under development attempt to discover the presence of an underwater target by transmitting an acoustic pulse and detecting the echo with a correlation receiver. This receiver correlates its input with time and frequency translates of a stored reference waveform, usually the same as the transmitted waveform. Owing to the presence of random multipath, there is usually not a single echo, but a multiplicity of echoes with random attenuations, time delays, and frequency shifts. Under these conditions, the detection capability of the correlation receiver is shown to be dependent upon the transmitted and reference waveforms. Necessary and sufficient conditions for optimum waveforms under a maximum signal-to-noise criterion with an energy constraint are derived. A technique for finding waveforms that satisfy only a necessary conditions is demonstrated, but it is conjectured that it produces the optimum waveforms. Conjectured optimum waveforms are derived for selected examples, and their performance compared to that of some conventional waveforms.

Comment: At attempt to make a more realistic correlation detection scheme by introducing a simple model of the ocean environment--that of random multipath reception in a noise-limited environment. The author promises extension of the scheme to reverberation-limited environments. Unfortunately, the assumption of random multipath reception is crucial to the results but is a poor model of a shallow-water channel.

I4 TIME AND FREQUENCY CHARACTERISTICS OF AN ACOUSTIC SIGNAL REFLECTED FROM A ROUGH BOUNDARY

J. J. Martin
J. Acoust. Soc. Am. 43, 405-417 (1968)

Abstract: This paper contains an analysis for determining the time of arrival and Doppler-frequency characteristics of a pulse transmitted to a target by reflection from a not-too-rough surface such as the sea bottom and gives numerical values for typical sonar applications. The analysis may be important in sonar signal processing associated with one-way or round-trip transmission and in the interpretation of data from marine geophysical surveys; it may, in addition, have application to propagation of electromechanical waves by ionospheric refraction.

Comment: "Not-too-rough" is constrained to mean". . . variances of surface elevation derivatives sufficiently small that there is no appreciable occulation of surface area at oblique incidence angles . . . it is necessary that surface correlation lengths be sufficiently great that at least the first Fresnel zone is nominally flat . . ." The analysis reveals the number of paths between source and target (for given sonar beam and geometry) depends on the variance and correlation length of surface slope; Doppler frequency depends on surface slope variance, primarily; some discussion of tailoring the sonar beam width or the pulse length and the effects on modifying the arrivals, the number of arrivals, and ranging errors is included.

I5 FLUCTUATIONS IN LOW-FREQUENCY ACOUSTIC PROPAGATION IN THE OCEAN

R. H. Nichols and H. J. Young
J. Acoust. Soc. Am. 43, 716-722 (1968)

Abstract: An experimental study has been made of the variability of acoustic transmission in the ocean at frequencies around 270 cps between a fixed bottomed source and fixed bottomed receivers. Transmitted signal level was observed at two distances: 2 and 700 NM (nautical miles), over periods ranging from 1 to 22 h. Simultaneous measurements were made at several hydrophones at each location to investigate correlation of fluctuations at various pair spacings. Two types of variation were noted. At the 2-mile range, quasiperiodic variations in level occurred with a predominant frequency of 0.12 cps, similar to that of surface waves. These are believed to be due to multipath interference of signals reflected one or more times from the moving surface. At the 700-NM range, such variations were also observed; in addition, large slower fluctuations were observed, with periods of a few minutes to several hours. These are believed to be due to changing multipath interferences among signals passing through moving or changing water masses of different refractive indices (e.g., internal waves). Cross-correlation coefficients of either type of fluctuation were small: 0.1 - 0.2 at pairs of hydrophones with spacings of 25 - 1815 ft.

Comment: The transmitter was placed in 200 f water off the shore of Eleuthera Island, beamed toward Bermuda. The receiver at 2 NM was also at 200 f, whereas the receiver at 700 NM was in 450 f water. For the short range, upward refraction precluded any direct path, so that the received signal was totally top and bottom reflected, with about four transmission paths. The received signal is thus interference-dominated and therefore phase-sensitive to a high degree.

I6 PHASE CHARACTERISTICS OF CONTINUOUS WAVE TRANSMISSION IN SHALLOW WATER

Lloyd C. Huff
J. Acoust. Soc. Am. 44, 650-651(L) (1968)

Abstract: Three temporal scales of phase stability are evident in shallow-water acoustic propagation of 1700-Hz signals transmitted across Block Island Sound.

Comment: The range was about 33 km long, and 40 meters in depth. The detected mechanisms for phase fluctuations, their magnitudes, and probable cause are quoted as:

± 1 rad/sec resulting from surface waves and path interference

± 60 rad/12 hr tide resulting from changes in propagation distance and path interference

±2000 rad/year resulting from changes in mean sound velocity and in propagation distance

I7 ON OPTIMUM WAVEFORMS FOR CORRELATION DETECTION IN THE SONAR ENVIRONMENT: REVERBERATION-LIMITED CONDITIONS

Thomas G. Kincaid
J. Acoust. Soc. Am. 44, 787-796 (1968)

Abstract: This study is concerned with optimum waveforms for correlation detection in the sonar environment. The selection of optimum waveforms for combating random multipath under noise-limited conditions was considered previously (T. G. Kincaid, J. Acoust. Soc. Am. 43, 258-268 (1968)). In this paper, the same problem is considered under reverberation-limited conditions. The optimum waveforms are required to maximize the ratio of expected signal to expected reverberation plus noise under a fixed-energy constraint. Necessary and sufficient conditions for the optimum waveforms are derived. As under noise-limited conditions, it has only been possible to develop a technique for finding waveforms that satisfy a necessary condition. However, it is conjectured that this technique produces

optimum waveforms. Conjectured optimum waveforms are found for selected examples, and their performance is compared to that of two conventional (CW and chirp) waveforms.

Comment: The essential assumptions include " . . . reverberation is due to individual point targetlike scatterers, and that in the absence of any medium effects, each scatterer echo would have associated with it the following random variables: round-trip amplitude attenuation, . . . round-trip time delay, . . . round-trip Doppler shift, . . . and round-trip phase shift. . . . these variables are independent of each other and of the medium random parameters . . ." Results are valid within the assumptions, which are disasterously limiting for shallow water environments, with well-defined top and bottom boundaries.

I8 PHASE AND AMPLITUDE FLUCTUATIONS IN PROPAGATING THROUGH A LAYERED OCEAN

Robert M. Kennedy
J. Acoust. Soc. Am. 46, 737-745 (1969)

Abstract: A propagation experiment was conducted over a 25-mile wide wholly refracted (RRR) path for 48 h in October 1967. The data recorded during the experiment consisted of both the arrival time and the amplitude of acoustic pulses at 11 vertically spaced hydrophones. The source and the receiver were fixed, and the medium was sampled every tenth of an hour with a 10-msec pulse at 800 Hz. The propagation path between source and receiver was purely refractive and amounted to a complete cycle of RRR type of propagation. The means, variances, autocorrelation, autospectral density, cross correlation, and coherence function were estimated for both the amplitude and phase data. The probability distribution function for both amplitude and phase is demonstrated to be nearly Gaussian. An interrelationship between the time and space characteristics of the random inhomogeneities of the medium is illustrated. Wherever possible, the measured results are compared with the theoretical values of Chernov (1960). A comparison of the theory, which is based on a statistically homogeneous medium, with the measured values obtained in a layered medium, is discussed.

Comment: The author states: "The major effect of propagating through a layered nonhomogeneous medium is that the acoustic wave encounters a spectrum of "patch" sizes as the wave cycles the ocean layers. The resulting fluctuations are thus a superposition of the effects of "patches" of various sizes."

I9 RAYS, MODES, INTERFERENCE AND THE EFFECT OF SHEAR FLOW IN UNDERWATER ACOUSTICS

D. E. Weston
J. Sound Vib. 9, 80-89 (1969)

Abstract: The relation between ray theory and modal interference theory is demonstrated for both isovelocity shallow water and for deep water with a linear positive sound-velocity gradient. This background eases the WKB calculation of the modal interaction or cycle distance for shallow water having a linear gradient.

The cycle distance has a maximum value, typically a few miles, for an equivalent grazing angle of a few degrees or a frequency of a few hundred Hz. The distance depends on the water depth, and also on the gradient and therefore the shear flow. These quantitites vary through the tidal cycle, so that for propagation between fixed points there is a changing interference pattern. Fluctuations from this cause have been observed in recent experiments, which gave evidence for the shear flow as well as the depth effects. Shear flow can also cause a failure in reciprocity. The main object of the present paper is to give the necessary theory in simple form, and to draw attention to the importance of the shear flow.

Comment: In this paper the author further refines his ideas about modal interference and comes up with a very lucid account. He explains the reduced attenuation which is observed in shallow water for frequencies of a few 100 Hz to be due to the fact that the number of bounces per unit range is minimized at these frequencies. Shear flow patterns associated with tidal currents are shown to have significant affects on acoustic propagation: they repeal the law of reciprocity and they alter the velocity gradient. Fluctuations are due both to the tidal depth changes and to the shear flow. "A knowledge of the shear flow is needed for any detailed prediction of the field in a shallow sound channel."

I10 EXPERIMENTS ON TIME-FREQUENCY INTERFERENCE PATTERNS IN SHALLOW-WATER ACOUSTIC TRANSMISSION

D. E. Weston, D. Smith and G. Wearden
J. Sound Vib. 10, 424-429 (1969)

Abstract: Sound in a frequency band from 4.1 kHz to 4.5 kHz was transmitted between a fixed source and fixed receivers, for ranges of 7 and 18 km in shallow costal water. Simultaneous records of sound level were made at 12 frequencies spaced 36 Hz apart, and the whole arranged to form a time-frequency display. One sample display clearly shows symmetrical patterns due to the changing interference of several normal modes. The patterns arise since the mode parameters depend on water depth, which in turn changes through the tidal cycle. The measured pattern slope agrees with predictions from a simple theory, and it is also possible to calculate the number of modes participating. Another pattern shows modifications which are explained in terms of the tidal flow.

Comment: This is a report of an experiment carried out in September 1959. It has taken nearly ten years of further experimentation in the same location and theoretical progress to develop the physical insights necessary for the interpretation of the results. (The evolution of this understanding is neatly set out in the references in this paper.) A very simple theory is developed to elegantly describe the temporal fluctuations as due to a spatially moving interference pattern. This interpretation is used to estimate the number of normal modes contributing to the sound field at each range.

I11 STUDIES OF SOUND TRANSMISSION FLUCTUATIONS IN SHALLOW COASTAL WATERS

D. E. Weston, A. A. Horrigan, S. J. L. Thomas and J. Revie
Phil. Trans. Roy. Soc. London, 265, 567-608 (1969)

Abstract: The propagation and fluctuation of sound have been studied in shallow coastal waters off the British Isles. The environment and the special environmental measurements are described. Acoustic measurements were made for various ranges between about 2 and 137 km, with bottom-laid transducers. Frequencies used were mainly 1, 2, and 3 kHz, most often transmitted continuously but sometimes pulsed. The investigations have extended over several years, and amplitude and phase fluctuations have been found with periods ranging from a year to less than a second. The nine fluctuation mechanisms which have been identified may be summarized as: (a) seasonal in amplitude, (b) seasonal in phase, (c) attenuation due to fish which sometimes causes a greatly reduced amplitude at night when the shoals break up, (d) storm effects, (e) tidal changes in depth which sweep an interference pattern past the receiver, (f) tidal changes in shear flow or the water structure which also affect the interference pattern, (g) phase effects due to tidal changes in the mean streaming velocity, (h) fluctuations of a few minutes period, some due to fish, (i) surface wave effects, which depend critically on the position in the tidal interference cycle. The above nine effects are really all subjects in their own right, and here large advances are described for seven of them. Most of the effects are both new and important, to be measured in many tens of decibels and in hundreds of phase cycles, but perhaps special attention should be drawn to the significance of the work on fish.

Comment: The authors state: "Fluctuations are of great practical importance because of their nuisance to the transmission of information ... . The nuisance is particularly great for systems which rely on the coherence of the medium." The experiments discussed in this paper were conducted over a period of almost a decade and they constitute one of the best examples of underwater research available in the literature. "The writers have become convinced of the tremendous advantages of having a site with fixed transducers, and of making long term studies." The significant results of this work clearly show that in the field of shallow-water acoustics, experimental research demands a long term commitment.

J. ATTENUATION OF SOUND IN SHALLOW WATER

J1 A BRIEF ANALYSIS OF THE EFFECT OF SUSPENDED SOLID PARTICLES ON SONAR PERFORMANCE IN VERY SHALLOW WATER

E. G. McLeroy
Navy Mine Defense Lab. (Report i-100) (1966)

Abstract: Calculations from existing theory are made of the changes in sound attenuation and velocity in water to be expected due to suspended solid particles of various concentrations. The possible effects of these phenomena on sonar propagation are considered and the effect on sonar performance is discussed. In general it appears that volume concentrations greater than 0.001 could have measurable effects on this performance.

J2 CONTRADICTION CONCERNING SHALLOW-WATER SOUND ATTENUATION

D. E. Weston
J. Acoust. Soc. 42, 526-527(L) (1967)

Abstract: For medium to long ranges in shallow water, and for frequencies above about 100 cps, energy is still present in at least the first two normal modes. The observed transmission laws cannot then be explained, as has been usual, by summing the normal modes with separate attenuations due to the boundary losses. The probable explanation is the presence of an enhanced body attentuation, possibly due to bladder fish.

Comment: A readable discussion of the mode-stripping model of shallow-water sound attenuation. Failure of this model to predict accurate loss-range relationships is used as an argument for an abnormally large volume absorption and an interesting source for this excess absorption is proposed. This theme is continued in the author's later work.

J3 SURFACE-COUPLED LOSSES IN SURFACE SOUND CHANNELS

Morris Schulkin
J. Acoust. Soc. Am. 44, 1152-1154(L) (1968)

Abstract: Evidence is presented that for a large body of surface sound-channel propagation data, corrected for ionic absorption, there is a residual attenuation coefficient that may be due to the combined effects of scattering by sea waves as well as bubble-layer absorption and scattering. The bubble-layer properties are wakelike and are dominant whenever they are present. The bubble-layer losses are proportional to the square root of the product of acoustic frequency and mean wave height.

Comment: It is shown that the AMOS transmission-loss data for shallow-water surface ducts can be correlated by plotting loss vs frequency x wave-height. The dependence on wave-height seems to invalidate Weston's fish-bladder explanation (see above). It is proposed that there exists a one-to-one relation between wave-height and surface bubble population and that these bubbles are responsible for the increased volume attenuation.

J4 SURFACE-COUPLED LOSSES IN SURFACE SOUND CHANNEL PROPAGATION. II

Morris Schulkin
J. Acoust. Soc. Am. 45, 1054-1055(L) (1969)

Abstract: In a previous Letter (M. Shulkin, J. Acoust. Soc. Am., 44, 1152(L) (1968)), an empirical relation was presented for wind-speed controlled losses in ocean-surface duct propagation, which holds over a wide range of frequencies (1.5 to 25 kHz) and wave heights. This relation is $a_s=1.64(fh)^{1/2}$ dB/limiting ray cycle where f is the acoustic frequency in kilohertz and h is the mean crest-to-trough waveheight in feet. In this Letter, evidence is presented that this behavior can result from the combined effect of (1) a bubble-density distribution with a tail that falls off approximately as $R^{7/2}$, where R is the bubble radius; (2) bubble-volume concentration decaying with depth z approximately as $z^{1/2}$ modified by a small dependence on layer depth and hydrostatic pressure; and (3) bubbles that mostly originate from breaking wind waves.

Comment: The observed surface-coupled attenuation coefficient is obtained by assigning a particular bubble-density distribution and depth dependence of bubble volume. The numbers that come from this theory are in reasonable agreement with the few data available for bubble populations in the ocean. It is assumed that the bubbles themselves do not bend the rays. (Isothermal water was assumed.) It is pointed out that pulse length and amplitude affect bubble measurements.

K. SONAR TESTS IN SHALLOW WATER

K1 SHALLOW WATER ACOUSTICS: FASOR I (U)

J. A. Whitney
(NEL Rept. 1388) (1966) CONFIDENTIAL

K2 AN/SQS-26 SONAR TESTS IN SHALLOW WATER UNDER DOWNWARD REFRACTION CONDITIONS (U)

B. F. Cole, J. G. Bell, and E. M. Podeszwa
USL Report No. 785, (1967) CONFIDENTIAL

L. REVIEW ARTICLES

L1 PREDICTING THE EFFECTS OF OCEANOGRAPHIC PARAMETERS ON SHALLOW WATER ACOUSTIC SYSTEMS

E. F. Johanson
In: Second U. S. Navy Symposium on Military Oceanography Proceedings, Vol. 2 Naval Ordnance Lab., Silver Spring, Md., 165-187, Washington, D. C., Naval Oceanographic Office (1965) CONFIDENTIAL

L2 REPORT ON THE STATUS OF PROJECT AMOS (ACOUSTIC, METERORОLOGICAL, AND OCEANOGRAPHIC SURVEY) (1 JAN. 1953-DEC. 1954)

H. W. Marsh and M. Schulkin
Underwater Sound Lab. Rept. 225A, 1-82 (1967)

L3 ASW SONAR TECHNOLOGY REPORT. SHALLOW WATER ACOUSTICS (U)

Arthur D. Little, Inc.
(Rept. 4241167) (1967) CONFIDENTIAL

Abstract: (U) This report reviews shallow water acoustics with special emphasis on propagation. Normal mode and ray theory solutions to the wave equation are considered as are most of the current empirical models for shallow water propagation. Comparisons are made to field data. In addition to propagation, the relationship between salinity, temperature, and sound velocity is examined and conclusions drawn about the use of velocimeters instead of bathythermographs by the fleet.

L4 THE PROPAGATION OF SOUND IN IMPERFECT OCEAN SURFACE DUCTS

Morris Schulkin
Navy Underwater Sound Laboratory, Report No. 1013, (1969)

Abstract: In this report, the author attempts to organize a field of knowledge. He reviews the field of the imperfect ocean surface sound duct and makes original contributions of detail where he believes that the greatest and most important needs exist. One of these contributions is the introduction of the concept of statistical reciprocity to explain the observed depth dependence of acoustic intensity within the duct at the higher frequencies. An expression is obtained for surface-coupled attenuation for acoustic propagation in surface ducts, and it is shown that bubble layers, established by wind and breaking waves, can be important in causing absorption losses. The author uses these facts, together with a model of strong acoustic scattering depending on the mean-square slope of the surface irregularities, to account for the acoustic intensity in the shadow zone below the surface duct. The importance of the mean-square slope parameter is also demonstrated by its use to account for wind-speed and acoustic frequency effects observed in acoustic back-scattering measurements, especially in the presence of a surface duct. In addition, the author evaluates the importance of wavy thermoclines, drift currents, and the biomass in relation to surface duct propagation.

M. MISCELLANEOUS ARTICLES

M1 ASWEPS SHALLOW WATER INVESTIGATION - VIRGINIA CAPES AREA

Naval Oceanographic Office
TR-208 (1967)

Abstract: The thermal structure of a rectangular area approximately 130 kilometers on a side over the Continental Shelf seaward of the Virginia Capes was investigated between 24 February and 11 March 1967. Sea surface temperature patterns agree with previous surveys in that isotherm orientation generally paralleled the coast with highest temperatures observed off shore. Zero or positive vertical temperature gradients predominated, but some transient negative gradients occured. Warm water in the southeastern quadrant of the survey area is probably Gulf Stream water advected northwestward into the survey area. The warm water moved northward during the survey. Chesapeake Bay discharge flowed seaward south of Cape Henry. On the basis of this survey, the development of thermal structure prediction techniques appears feasible providing a knowledge of local conditions and sufficient synoptic data are available.

M2 BIBLIOGRAPHY AND REVIEWS OR ABSTRACTS OF ARTICLES ON UNDERWATER SOUND TRANSMISSION, DETECTION AND IDENTIFICATION: 1956-1966

Johann Martinek, Herman J. Mecklenberg, and Paul W. Broome
A Teledyne Company, Report No. ARL 3-67 (1967)

Comment: Reviewed in J. Acoust. Soc. Am. 43, 903-904 (1968) by D. C. Whitmarsh, ORL, Penn. State University. Survey of the open literature, including that of the Soviet Union, for the above-mentioned years. There are 1930 references from 343 journals and other publications.

M3 A PREDICTION MODEL FOR THE PERFORMANCE OF SONARS IN SHALLOW WATER

A. E. Dan and S. E. Gottlieb
Operations Research Inc., TR 418 (1967)

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13. ABSTRACT

A survey was conducted of that literature relevant to the propagation, detection, and utilization of acoustic signals in the shallow water environment which was published between January 1965 and December 1969. For the purpose of this survey, shallow water was defined as water of depth less 600 FT than 100 fathoms. This survey is divided into the following areas: normal mode propagation - theory and experiment, ray theory propagation - theory and experiment, bottom acoustics, bottom scattering and reverberation, surface scattering and reverberation, shallow water ambient noise, signal distortion in shallow water, attenuation of sound in shallow water, sonar tests in shallow water, and review and miscellaneous articles. Abstracts, when available, are given for each paper; comments are included.

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